ISPRS Journal of Photogrammetry and Remote Sensing 108 (2015) 172–182

Contents lists available at ScienceDirect

ISPRS Journal of Photogrammetry and Remote Sensing

journal homepage: www.elsevier.com/locate/isprsjprs

Comparison of positioning accuracy of a rigorous sensor model and two rational function models for weak stereo geometry

Jaehoon Jeong [a,*], Taejung Kim [b]

[a] Korea Ocean Satellite Center, Korea Institute of Ocean Science and Technology, 787 Haeanro, Sangnokgu, Ansan 426-744, Republic of Korea
[b] Department of Geoinformatic Engineering, Inha University, 100 Inharo, Namgu, Incheon 402-751, Republic of Korea

ARTICLE INFO

Article history:
Received 17 April 2015
Received in revised form 27 July 2015
Accepted 28 July 2015
Available online 12 August 2015

Keywords:
Positioning accuracy
Stereo geometry
Rigorous sensor model (RSM)
Rational functional model (RFM)
Satellite imagery

ABSTRACT

So far, two sensor models for the geometric modeling of satellite imagery have been studied and compared: a rigorous sensor model (RSM) and a rational function model (RFM). Even though it was concluded that the RFM could replace the RSM, this paper points out that the previous conclusions were drawn only for a strong geometry because of the conventional use of single-sensor stereo and that they may not apply to the weak geometry of dual-sensor stereo pairs. This work highlights that dual-sensor stereo often creates a weak geometry and that for such weak geometry, accuracy differences may occur between the RSM and the RFM, and also between the RFMs with different bias correction methods. The positioning accuracy of the three sensor models, RSM, RFM using second-order polynomials model, and RFM using an affine model, were compared on various geometries, using pairs from every conceivable combination of two QuickBird and IKONOS as well as four KOMPSAT-2 images covering the same area. Our results showed that the three sensor models differed slightly owing to the strong geometry. However, for the weak geometry, the RSM or second-order RFM performed better than RFM with an affine model, resulting in increase in the difference between the accuracies of the sensor models. This implies that the physically weak geometry of a satellite stereo may require a rigorous or high-order model for a more accurate geo-positioning.

© 2015 International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS). Published by Elsevier B.V. All rights reserved.

1. Introduction

Sensor modeling for remote sensing image data can be defined as the procedure that establishes the geometric relationship between the image coordinates and their corresponding ground coordinates. To implement the accurate geo-positioning from satellite stereo pairs, appropriate sensor models are required. Therefore, sensor models have been studied extensively to report or improve the positioning accuracy of various satellite images (Gugan and Dowman, 1988; Radhadevi et al., 1998; Fraser et al., 2002a,b; Grodecki and Dial, 2003; Fraser et al., 2006; Kim and Dowman, 2006; Sultan and Gruen, 2008; Eckert, 2009; Crespi et al., 2012; Poli and Toutin, 2012).

In general, sensor models for satellite imagery can be largely categorized into two types: rigorous sensor models (RSM), also called physical sensor models, which contain model equations based on ephemeris data (e.g., satellite position, velocity, and attitude angles) (Radhadevi et al., 1998; Kim and Dowman, 2006) and rational function models (RFM), also called generalized sensor models, which contain model equations based on rational polynomial coefficients (RPCs) provided by the vendor (Grodecki and Dial, 2003; Fraser et al., 2002a,b; Fraser and Ravanbakhsh, 2009). While RFMs may be comparatively simple as they are directly defined by the RPCs, RSMs are more complex as they require many mathematical calculations that involve physical entities for the image acquisition process.

Since the beginning of satellite imagery use, RSMs have been recognized as the most precise models for accurate positioning. In particular, two types of RSMs were widely used: the first was based on modified collinearity equations (Gugan and Dowman, 1988; Orun and Natarajan, 1994) and the second was based on satellite orbital parameters and attitude angles (Radhadevi et al., 1998). While the first used the satellite position and rotations about the Cartesian coordinates axes of an object space reference frame as model parameters, called the "position-rotation (PR) model;" the second used satellite position, velocity, and attitude angles as model parameters, called the "orbit-attitude (OA) model" (Kim and Dowman, 2006; Kim et al., 2007). The attitude angles in the OA model represent actual physical movements of the satellite,

---

* Corresponding author. Tel.: +82 31 400 7773.
E-mail addresses: jaehoon@kiost.ac (J. Jeong), tezid@inha.ac.kr (T. Kim).

http://dx.doi.org/10.1016/j.isprsjprs.2015.07.006
0924-2716/© 2015 International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS). Published by Elsevier B.V. All rights reserved.

whereas the rotations in the PR model are not truly “physical.” Moreover, the actual physical moves are oversimplified by modifying the collinearity equation that was originally proposed and used for modeling perspective images. The performance of both RSMs was validated in several studies including one mentioned above and compared in Kim and Dowman (2006). These studies supported the idea that RSMs are necessary for precise positioning because of their capability to fully interpret the geometric relationship between the image and the object space.

However, the RSMs contain numerous mathematical estimations and may require specialized model equations for each sensor. To avoid such complex mathematics and easily handle the increase in satellite imagery, the RFM that is a generalized sensor model and is considered as an approximate solution for the RSM was suggested (Chen et al., 2006). It uses the ratios of polynomials to approximate the orbital parameters, and was adopted as a standard sensor model for IKONOS images (Dial and Grodecki, 2002). Since then, a number of studies have validated the wide use of the RFM for the precise positioning of satellite images (Grodecki and Dial, 2003; Fraser and Yamakawa, 2004; Tao et al., 2004). Nevertheless, some debate remains concerning the full replacement of the RSM by the RFM under the lack of rigorous interpretation of physical positioning and sensor attitude. Hence, comparisons between the two sensor models have been carried out to convince remote sensing users to accept the RFM as a valid alternative to the RSM.

Chen et al. (2006) compared the geometric accuracy of the two sensor model types using FORMOSAT-2 satellite images. The RSM was based on the state vector approach (Chen and Chang, 1998), while the RFM used an affine transformation to compensate for the errors in the image space due to the systematic bias of RPCs (Fraser and Hanley, 2003). They checked and compared the error of the two model types and concluded that the model accuracy of the RFM was similar to the RSM. Nagasubramanian et al. (2007) compared the performances of the RSM and the RFM for a long strip of LISS-2 imagery. The orbit-attitude model and an affine correction model for bias compensation were adapted for the RSM and the RFM, respectively. They demonstrated the potential of the RFM as a replacement sensor model by comparing their accuracies. Teo (2011) also compared the three bias-compensated models for the geometric correction of QuickBird, WorldView-1, and WorldView-2 Basic images. The three models included the bias-compensated RSM in the orbital and image space, and the bias-compensated RFM in the image space. Their results indicated that the bias-compensated RFM had a similar accuracy as that of the bias-compensated RSM in the image space and just a slightly lower accuracy as compared to the bias-compensated RSM in the orbital space. Another study has showed the potential of the RFM for recovering rigorous sensor model data (Di et al., 2003). Overall, the previous comparisons have supported the substitution of the RSM by the RFM for many mapping applications.

Here, we need to note that the previous conclusions were drawn only for the strong and stable geometries of conventional single-sensor stereo that uses two images taken from an identical sensor. However, such strong geometries were not always guaranteed while using the stereo pair, particularly when dealing with the dual-sensor stereo that uses two images taken from sensors on two different satellites. For example, a dual-sensor stereo often creates a very weak and unstable geometry (Jeong and Kim, 2014). Considering the increase in satellite imagery and in the flow of sensor integration in remote sensing applications, it is important to compare the performance of the sensor models for such weak and unstable geometries. This will lead to the effective use of sensor models for various geometric conditions and enhance the applicability of satellite images in the mapping application.

Little research on such comparison has been made for the weak and unstable geometry so far although a few studies have handled dual-sensor images. Li et al. (2007, 2009) have reported the positioning accuracy of dual-sensor stereos by integrating IKONOS and QuickBird images, but only for the RFM, partly due to their ability to easily handle the dual-sensor images. Li and Batchvarova (2008) analyzed the mapping accuracy achieved by combining the single images of IKONOS, QuickBird, and SPOT-5. However, they mainly examined the potential of 3D affine model for mapping using such image combination at different resolutions. In a recent study, the positioning accuracy of the RSM and RFM was suggested for the dual-sensor stereos (Jeong and Kim, 2014). However, since the primary concern of the study was to investigate the dual-sensor stereo geometry and its positioning accuracy, only a brief discussion on the comparison of the two sensor models for a limited number of cases was presented. Further study is necessary in order to conclude the accuracy difference between the sensor models for various stereo geometries before their uses can be approved for all the geometries.

In this paper, three sensor models, RSM using orbital parameters, RFM using second-order polynomials model and RFM using an affine model, are compared for the positioning accuracy under various stereo geometries created from twenty-seven stereo pairs: seven single-sensor stereos and twenty dual-sensor stereos. In particular, this paper aims to identify the accuracy difference between the sensor models for handling weak stereo geometries, which is still a challenging task. The experiment examines the potential of the RFM with an affine model, the widely used correction model, to replace the RSM, and also examines whether such an RFM has any difference from the RFM with higher-order terms, for weak and unstable geometry.

The paper is organized as follows: Section 2 briefly describes the test data and the sensor models used in this study; Section 3 compares the positioning accuracies of the sensor models for various stereo geometries using single-sensor and dual-sensor stereo pairs; and Section 4 presents our conclusions.

2. Test data and sensor models used

In our experiments, two QuickBird and IKONOS, and four KOMPSAT-2 images covering the same area of Daejeon, Korea were used. The QuickBird images were processed at Level-1 (basic), the IKONOS images at Level Standard Geometrically Corrected, and the KOMPSAT-2 images at Level-1R. The properties of the images are listed in Table 1 with the scenes numbered by acquisition time order. Fig. 1 presents the sensors’ positions using the azimuth and elevation angles, and altitude, available from on-board ephemeris data. The two QuickBird images were taken with along-track viewing angles of −27.6° and 29.2°, respectively, while maintaining an across-track viewing angle close to 0°. The four KOMPSAT-2 images were taken with roll angles of 14.3°, −28.4°, −13.7°, and −16.8°, while maintaining a pitch angle close to 0°. The images were taken at two opposite directions, by tilting the satellite in only one direction, along-track (pitch) or across-track (roll), without tilting in the other direction. Although the two IKONOS images were not taken at opposite directions while tilting along-track and across-track viewing angle simultaneously, they were also taken with regular azimuth angle interval by maneuvering the system (Table 1). These conditions allow a stable and strong geometry, with the normal range of convergence and BIE angles, for the single-sensor stereos.

On the contrary, dual-sensor stereo pairs that are constructed randomly without such geometric conditions produce various (and often very unstable and weak) geometries (Jeong and Kim, 2014). For example, it can be expected from Fig. 1 that various forms of epipolar planes will be constructed with the random selection for combination of one KOMPSAT-2 and one QuickBird

Download English Version:

https://daneshyari.com/en/article/6949394

Download Persian Version:

https://daneshyari.com/article/6949394

Daneshyari.com